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(54) **OPTICAL MODULE AND OPTICAL TRANSMITTER**

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(71) Applicant: **FUJITSU OPTICAL COMPONENTS LIMITED**, Kawasaki-shi, Kanagawa (JP)

(72) Inventors: **Masaki Sugiyama**, Sagamihara (JP);  
**Seimi Sasaki**, Sagamihara (JP);  
**Takehito Tanaka**, Yokohama (JP)

(73) Assignee: **FUJITSU OPTICAL COMPONENTS LIMITED**, Kawasaki (JP)

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(58) **Field of Classification Search**

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See application file for complete search history.

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*Primary Examiner* — Agustin Bello

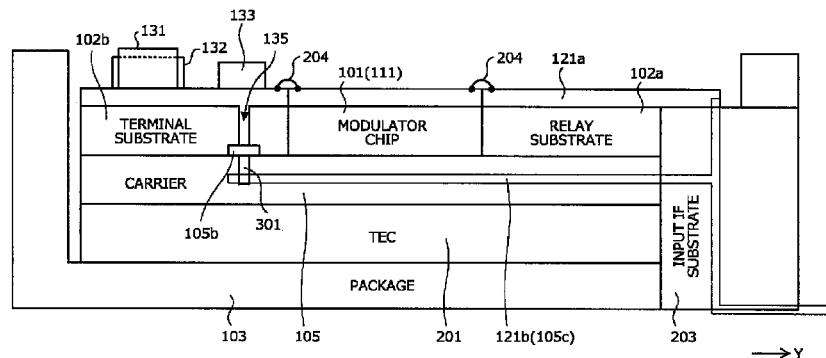
(74) *Attorney, Agent, or Firm* — Staas & Halsey LLP

(57)

**ABSTRACT**

An optical module includes a waveguide substrate including an optical waveguide and electrodes that apply electronic signals to the optical waveguide; a relay substrate disposed adjacent to the waveguide substrate; a terminal substrate disposed adjacent to the waveguide substrate and opposite to the relay substrate across the waveguide substrate; and a carrier substrate on which the waveguide substrate, the relay substrate, and the terminal substrate are mounted. The electrodes have a first interconnect unit from the relay substrate to the terminal substrate via the waveguide substrate and second interconnect units from the first interconnect unit and branching on the terminal substrate. Among the second interconnect units, a first interconnect branch includes a capacitor and a terminal resistor; and a second interconnect branch is connected to an interconnect of the carrier substrate via a bias resistor, passes under the waveguide substrate to a DC electrode for bias-adjusting on the relay substrate.

**14 Claims, 13 Drawing Sheets**



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FIG. 2

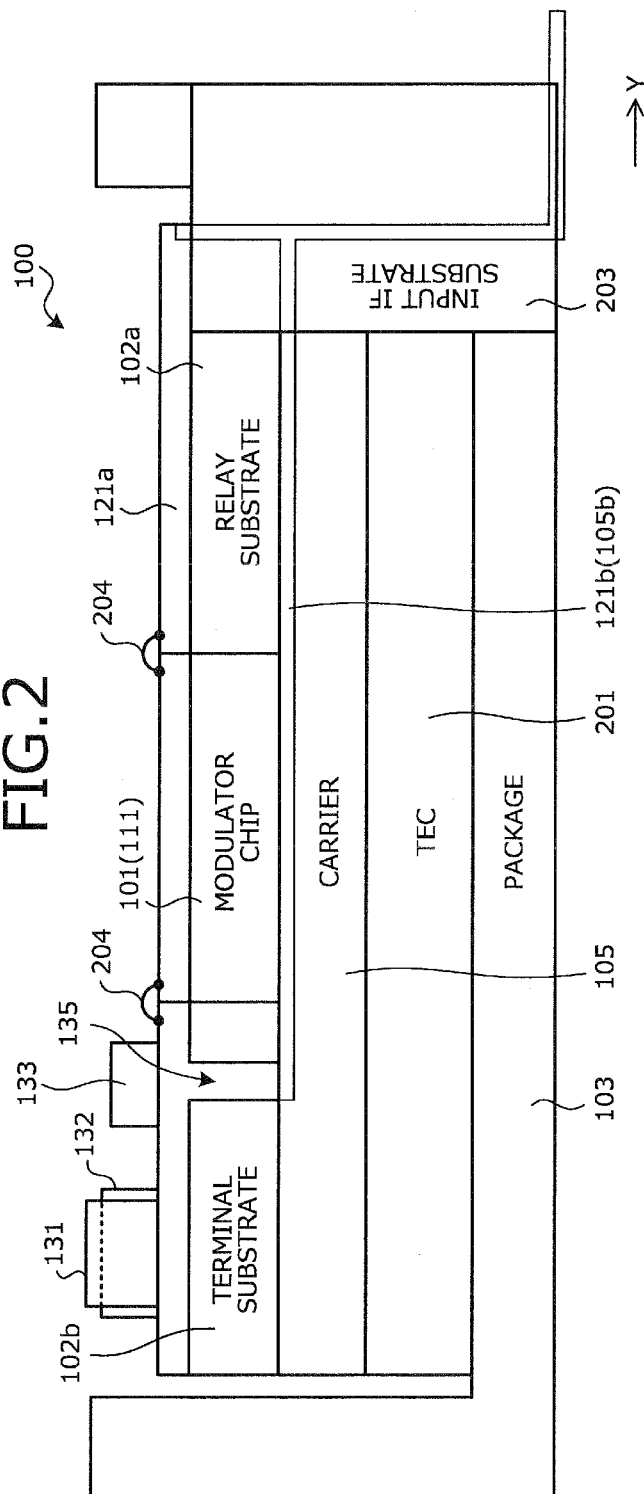
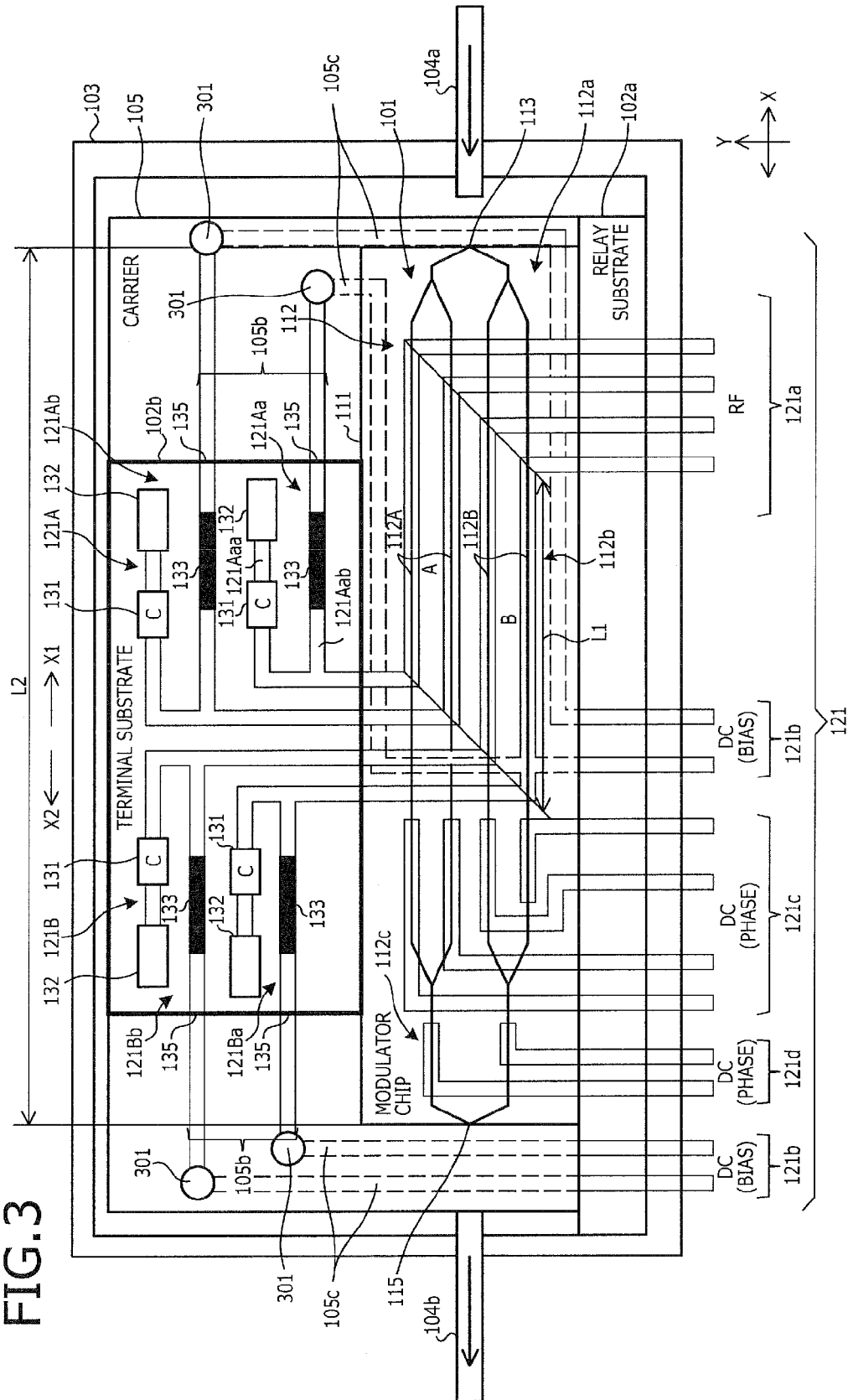


FIG. 3



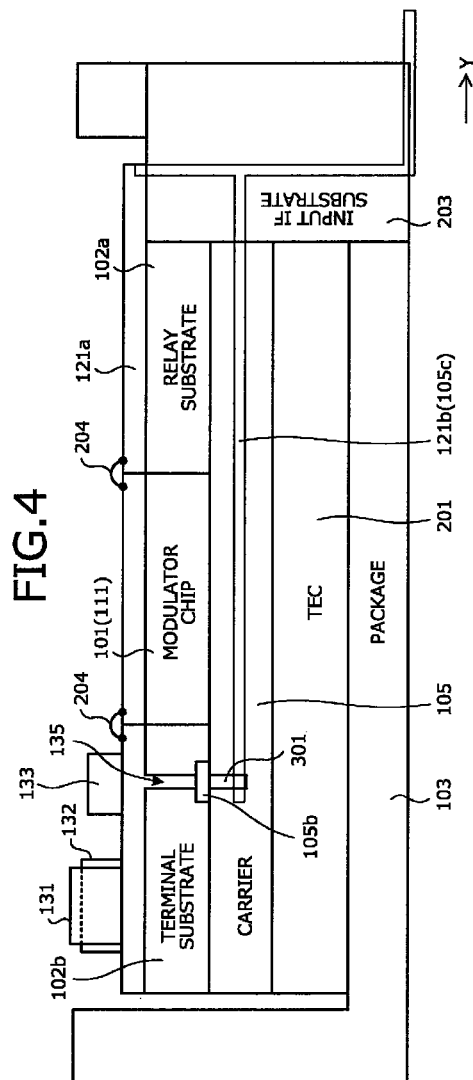


FIG. 5.

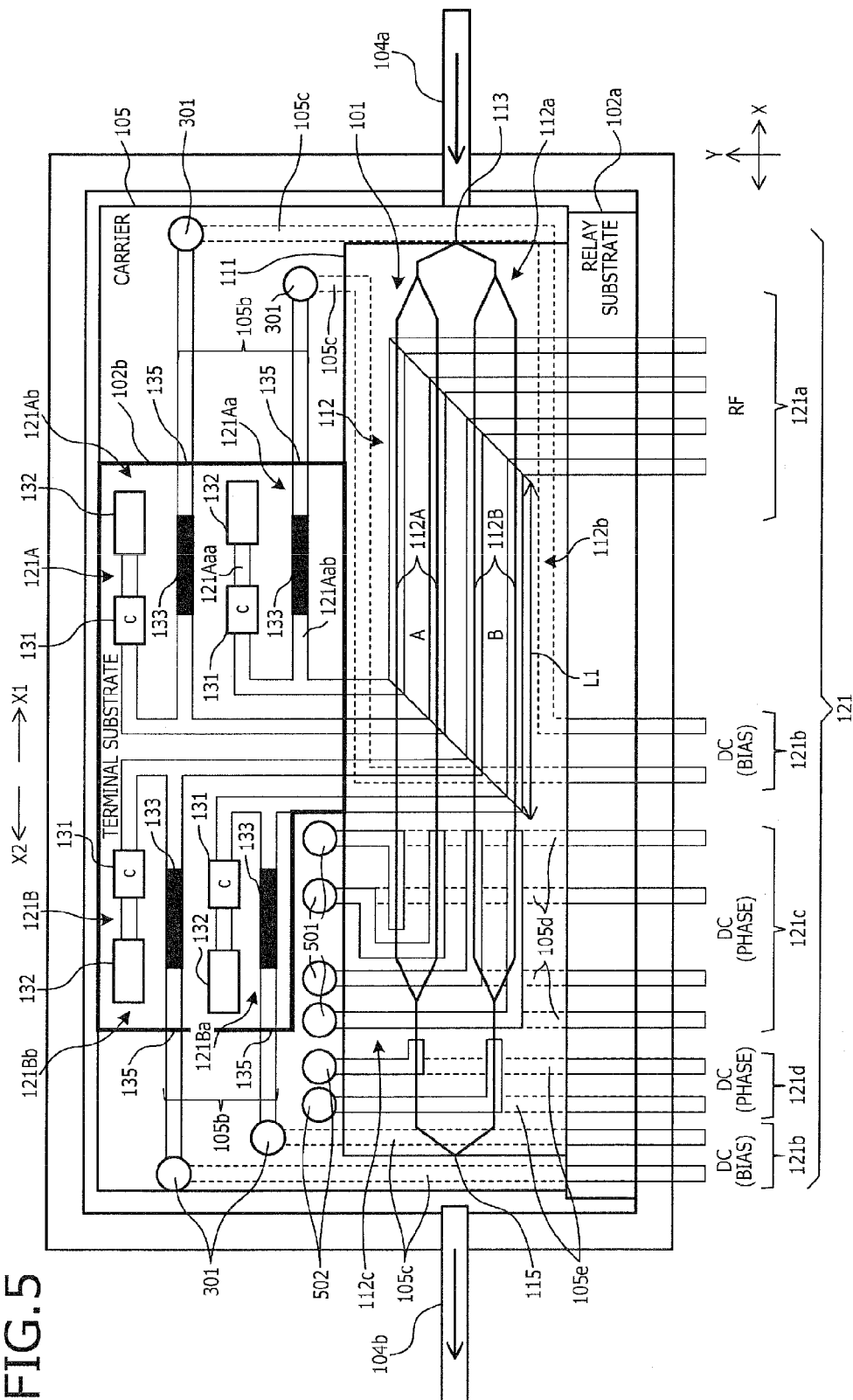


FIG. 6.

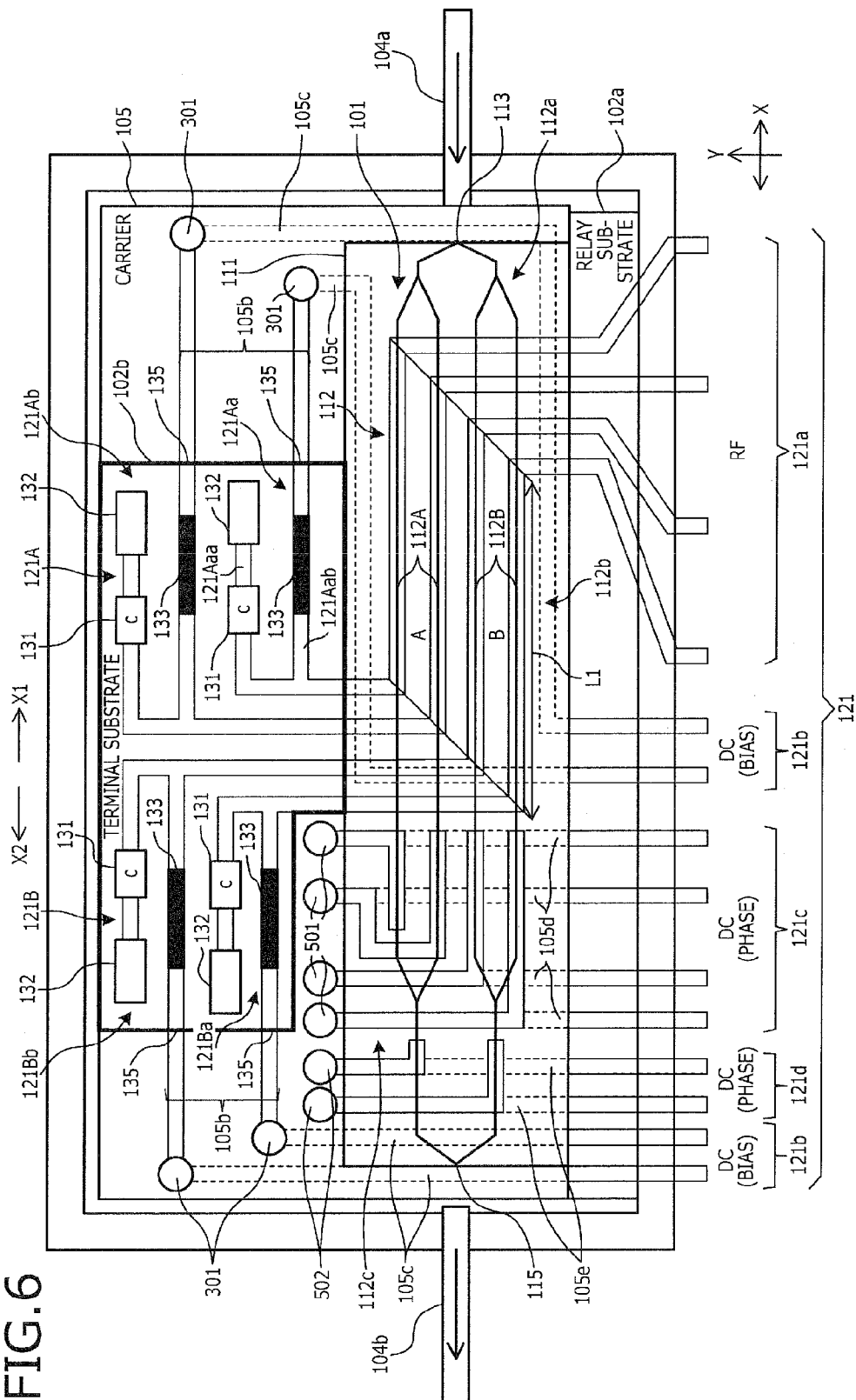




FIG. 7

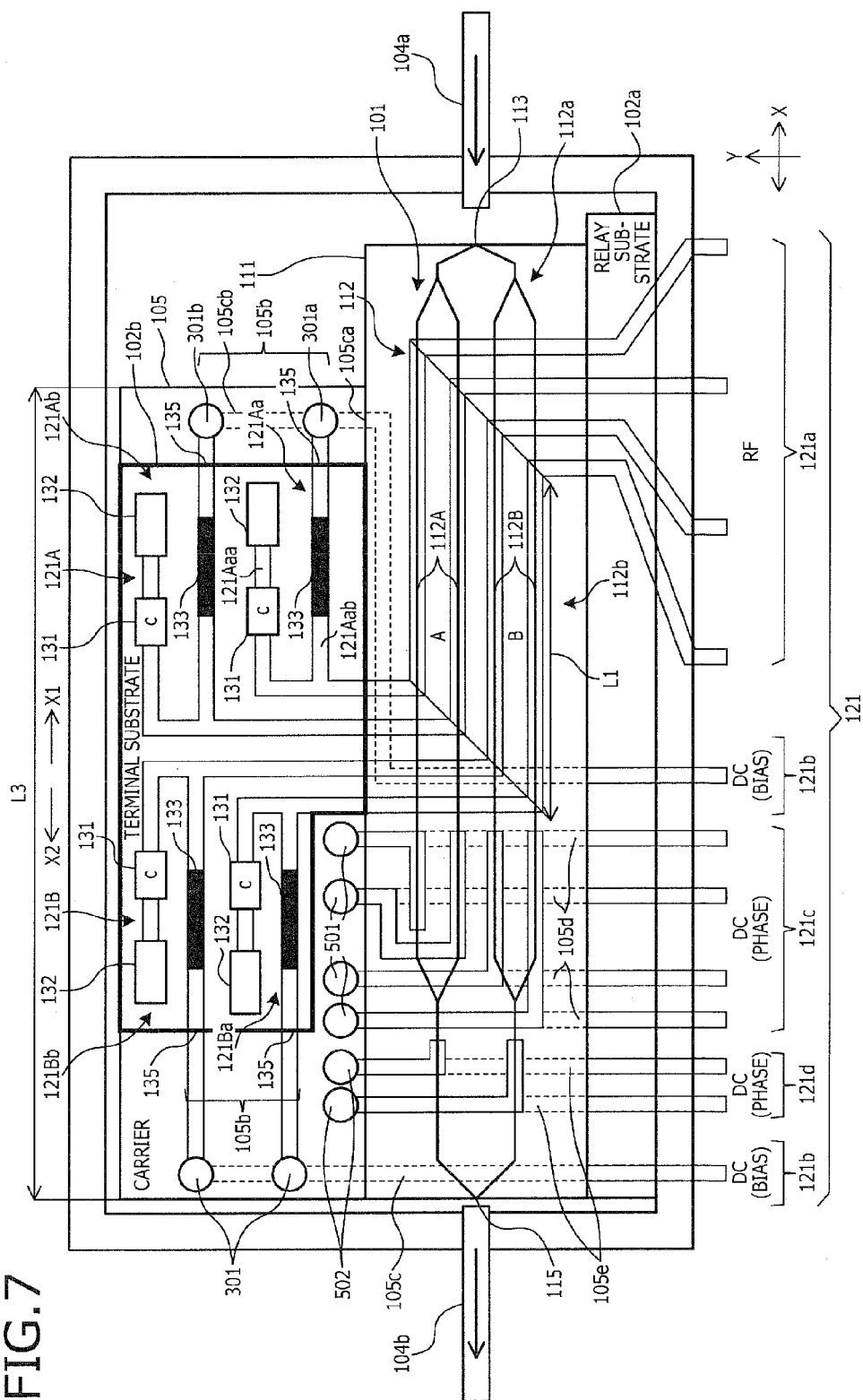


FIG. 8

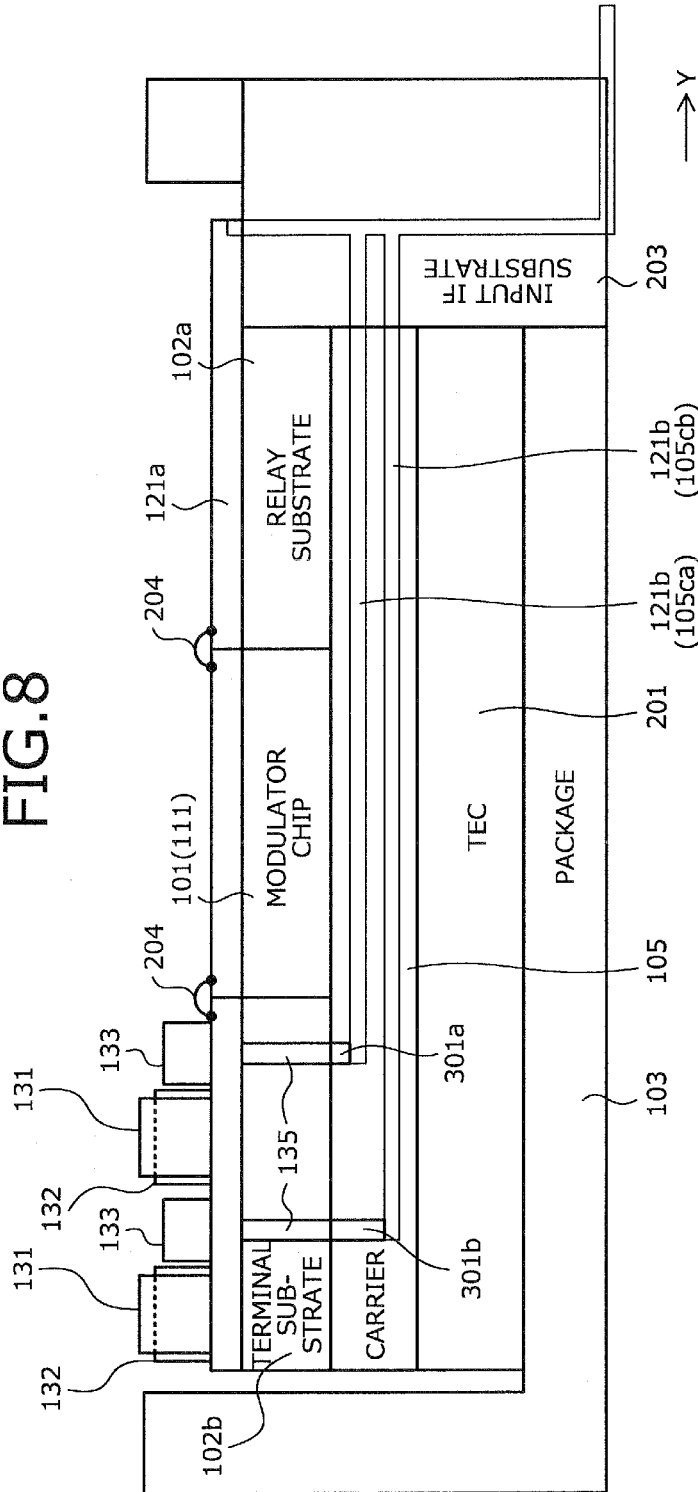


FIG. 9.

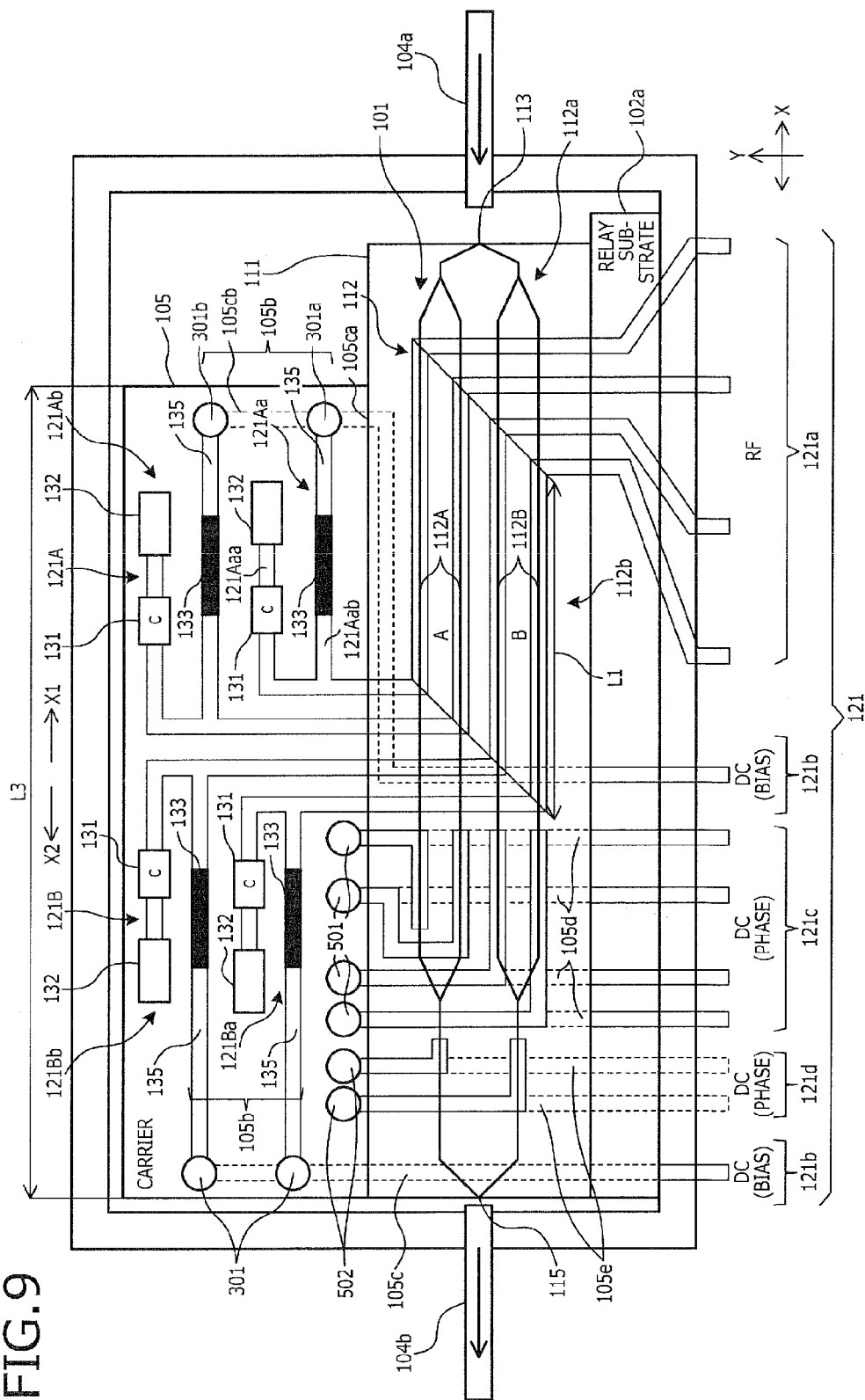


FIG. 10

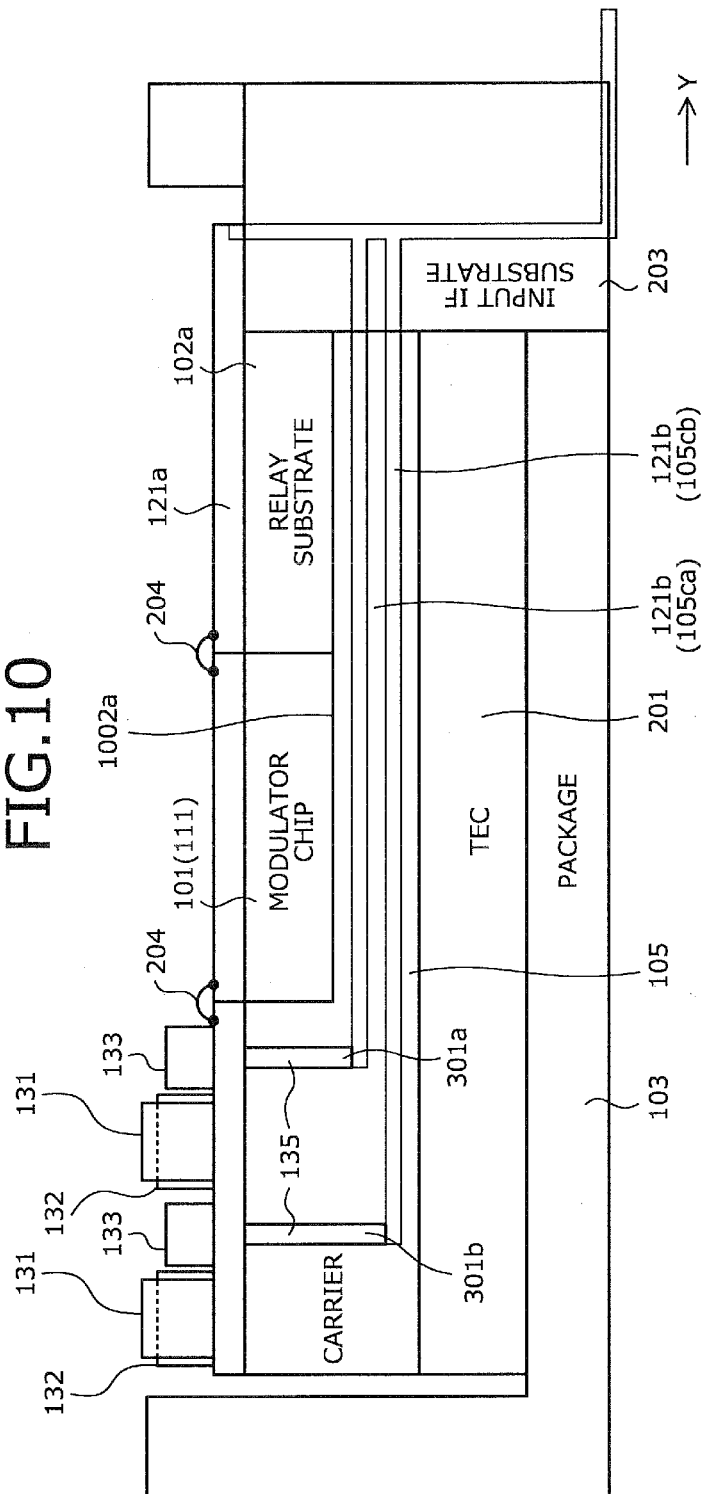


FIG. 11

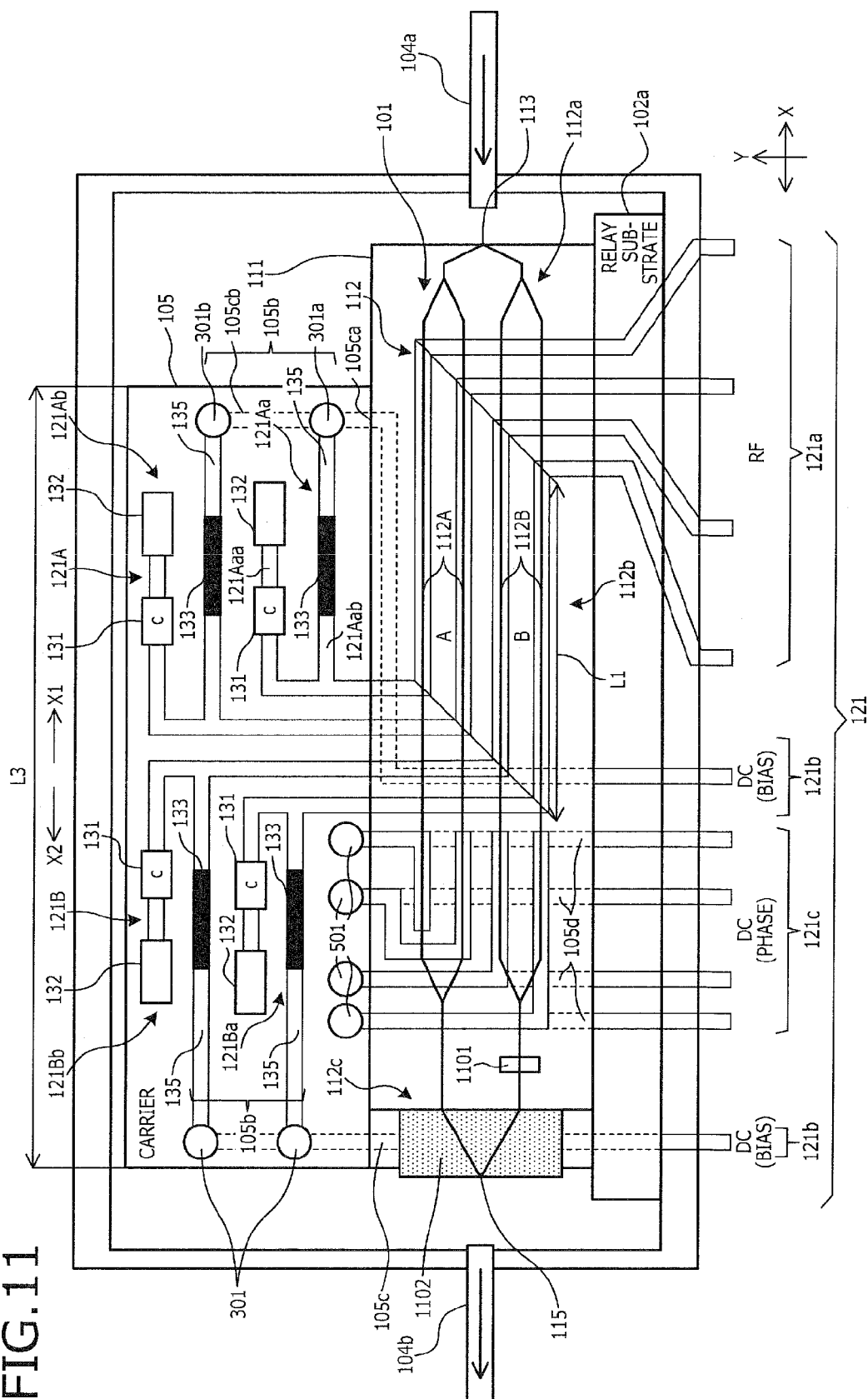


FIG. 12

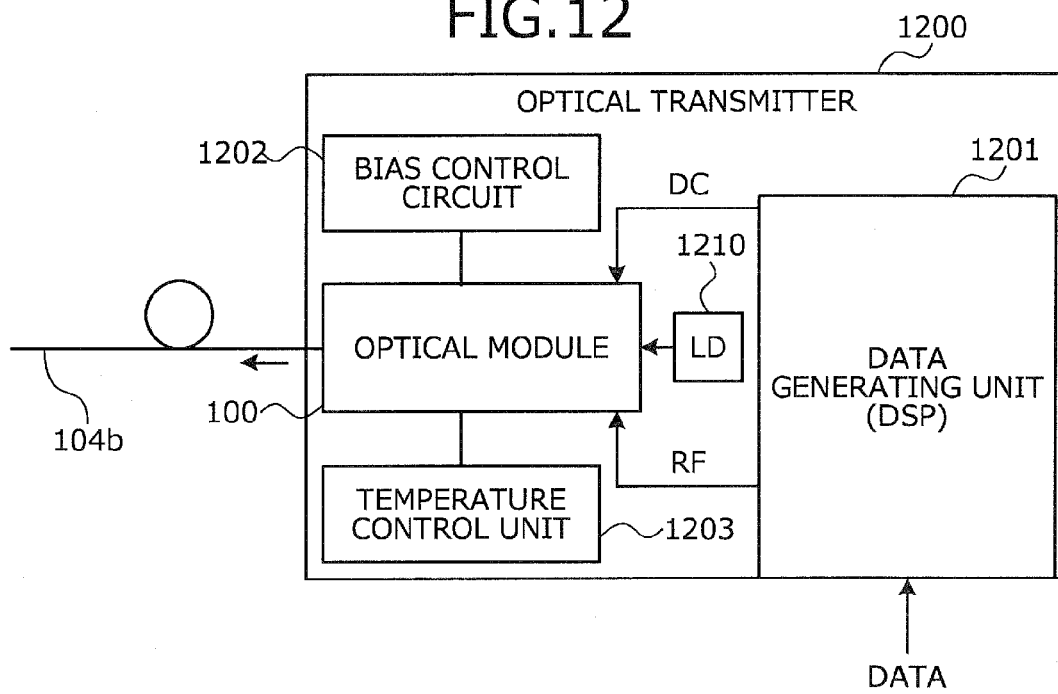
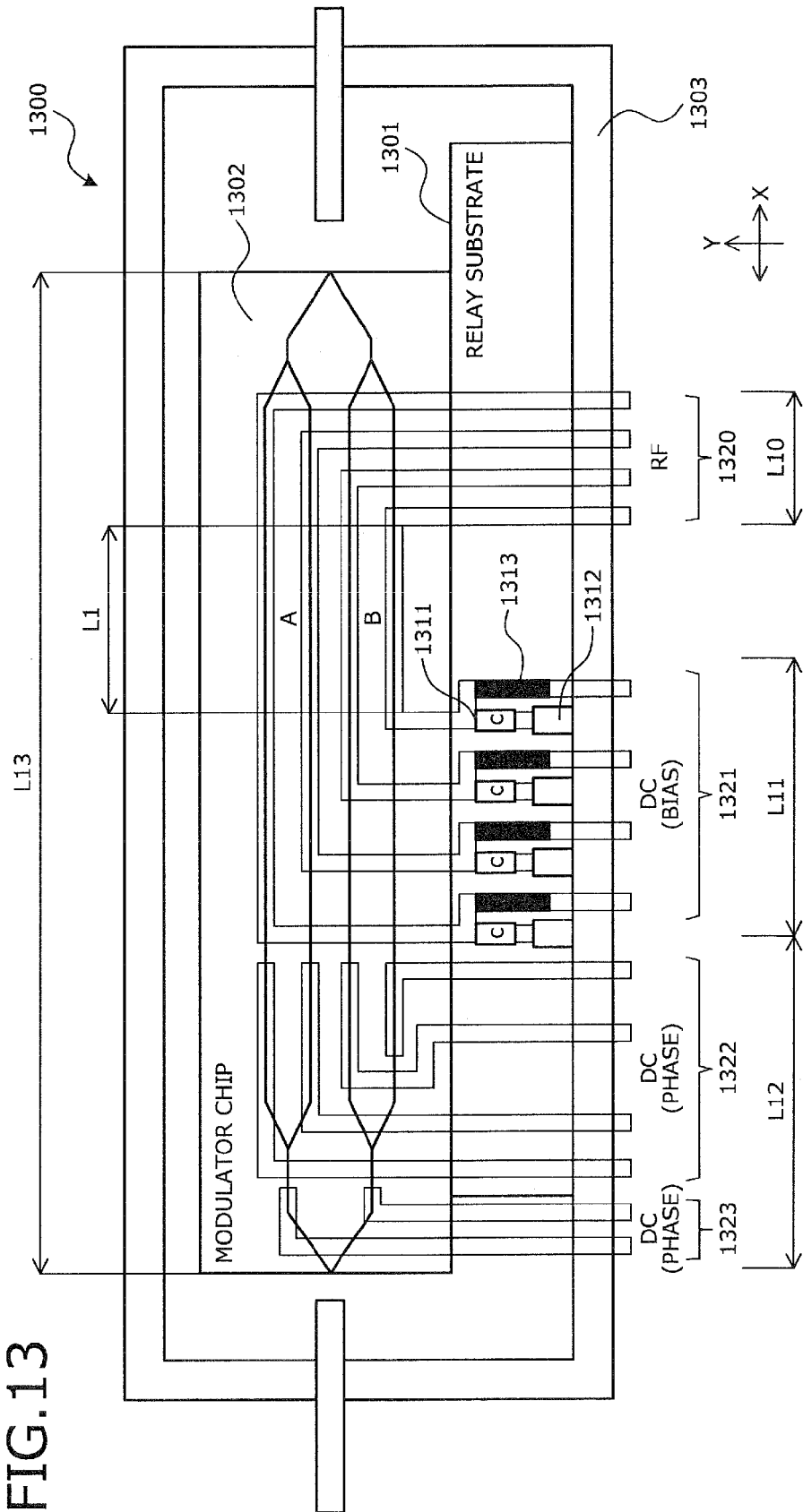


FIG. 13



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**OPTICAL MODULE AND OPTICAL TRANSMITTER****CROSS REFERENCE TO RELATED APPLICATIONS**

This application is based upon and claims the benefit of priority of the prior Japanese Patent Application No. 2013-190563, filed on Sep. 13, 2013, the entire contents of which are incorporated herein by reference.

**FIELD**

The embodiments discussed herein are related to an optical module and an optical transmitter used in optical transmission.

**BACKGROUND**

An optical waveguide device using, for example, an electrooptical crystal substrate, such as an  $\text{LiNbO}_3$  (LN) substrate and  $\text{LiTaO}_2$  substrate, or a semiconductor substrate, such as GaAs substrate and InP substrate, is known as an optical module. This optical waveguide device is created by forming a metal film made of titanium (Ti) on part of the substrate and causing the film to thermally diffuse, or by executing proton exchange in a benzoic acid after patterning treatment. An electrode is then formed near the optical waveguide to construct the optical module, such as optical modulator.

When such an optical modulator is driven at high speed, the terminal of a signal electrode is assumed to be connected to the terminal of a ground electrode via resistance, thereby forming a traveling wave electrode, and a high-speed microwave signal (electronic signal) is applied from the input side to an RF terminal. At this time, an electric field shifts the refraction factors of a pair of parallel waveguides A and B by  $+\Delta$  and  $-\Delta$ , respectively, which consequently shifts the phase difference between the parallel waveguides A and B. In this manner, the signal passing through a Mach-Zehnder interferometer is output from an outgoing waveguide, as intensity-modulated signal light.

By matching the speed of light and the speed of the high-speed microwave signal (electronic signal), high-speed optical response characteristics can be achieved. After traveling through the optical modulator, the electronic signal travels through a capacitor and is terminated at a terminal resistor. Before the capacitor, the electrode is branched into one portion that extends through a bias resistor to be connected to a DC terminal and the other portion that is terminated at a terminal resistor. The optical modulator with this configuration functions as a bias. By applying a voltage to the DC terminal, a bias point and a drive voltage of the Mach-Zehnder unit can be controlled.

Such an optical modulator includes a Mach-Zehnder modulator unit and a relay substrate to which an electronic signal for driving the Mach-Zehnder modulator unit is input. As a technique related to the relay substrate, for example, a technique is known according to which the Mach-Zehnder modulator unit is disposed between a signal input substrate and a signal terminating substrate having a terminal resistor, etc. (see, e.g., Japanese Laid-Open Patent Publication Nos. 2007-139987 and 2003-015096). Another technique is also known according to which a signal input substrate and a signal terminating substrate are disposed on one side of a modulator (see, e.g., Japanese Laid-Open Patent Publication No. 2003-295139). Still another technique is also known according to which a relay substrate is provided as a unit

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separated from to an optical modulator unit and electrode intervals between RF terminals on the relay substrate are widened (see, e.g., Japanese Laid-Open Patent Publication No. 2010-185979).

In recent years, accompanying advances in techniques for multi-value processing and optical-polarization division multiplexing aimed at large-capacity optical communication, the configuration of the modulator has become more complicated. For example, a modulation method is adopted for the modulator such that two sets of Mach-Zehnder modulator units each having a pair of parallel waveguides are provided and an independent signal is input to the two sets of Mach-Zehnder modulator units to generate multi-value signals multiplexed by optical-polarization division.

According to the configuration that includes the two sets of Mach-Zehnder modulator units, however, the number of signal paths for electronic signals is doubled on a substrate having the Mach-Zehnder modulator units, which brings about a need for space to arrange the signal paths. Accordingly, the number of RF terminals, DC terminals, capacitors, bias resistors, and terminal resistors is also doubled on the relay substrate. This brings about a problem in that the size of the relay substrate, e.g., a length along the parallel waveguides of the Mach-Zehnder modulator units increases and the size of a module accommodating the Mach-Zehnder modulator units increases as well.

**SUMMARY**

According to an aspect of an embodiment, an optical module includes a waveguide substrate including an optical waveguide and electrodes that apply an electronic signal to the optical waveguide; a relay substrate disposed adjacent to the waveguide substrate; a terminal substrate disposed adjacent to the waveguide substrate and opposite to the relay substrate across the waveguide substrate; and a carrier substrate on which the waveguide substrate, the relay substrate, and the terminal substrate are mounted. The electrodes have a first interconnect unit extending from the relay substrate to the terminal substrate via the waveguide substrate and second interconnect units extending from the first interconnect unit and branching on the terminal substrate. A first interconnect branch among the second interconnect units includes a capacitor and a terminal resistor, and a second interconnect branch among the second interconnect units is connected to an interconnect of the carrier substrate via a bias resistor, passes under the waveguide substrate, and extends to a DC electrode, bias-adjusting, on the relay substrate.

The object and advantages of the invention will be realized and attained by means of the elements and combinations particularly pointed out in the claims.

It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory and are not restrictive of the invention.

**BRIEF DESCRIPTION OF DRAWINGS**

FIG. 1 is a top view of an optical module according to a first embodiment;

FIG. 2 is a side sectional view of the optical module according to the first embodiment;

FIG. 3 is a top view of the optical module according to a second embodiment;

FIG. 4 is a side sectional view of the optical module according to the second embodiment;

FIG. 5 is a top view of the optical module according to a third embodiment;



FIG. 6 is a top view of another optical module of the third embodiment;

FIG. 7 is a top view of the optical module according to a fourth embodiment;

FIG. 8 is a side sectional view of the optical module according to the fourth embodiment;

FIG. 9 is a top view of the optical module according to a fifth embodiment;

FIG. 10 is a side sectional view of the optical module according to the fifth embodiment;

FIG. 11 is a top view of the optical module according to a sixth embodiment;

FIG. 12 is a block diagram of a configuration example of an optical transmitter according to a seventh embodiment; and

FIG. 13 is a top view of a configuration example of another optical module for comparison with the optical module of the embodiments.

### DESCRIPTION OF EMBODIMENTS

Embodiments of an optical module and an optical transmitter will be explained in detail with reference to the accompanying drawings.

FIG. 1 is a top view of an optical module according to a first embodiment, and FIG. 2 is a side sectional view of the optical module according to the first embodiment. This optical module 100 is an example of a configuration of a QPSK optical modulator, and includes a Mach-Zehnder modulator unit (modulator chip) 101, an electrode substrate 102, an enclosure (package) 103 housing the Mach-Zehnder modulator unit 101 and electrode substrate 102, input/output optical fibers 104 (104a and 104b), and a carrier (substrate) 105. Multiple terminals (RF terminals and DC terminals, which will be described later) are formed on the electrode substrate 102.

On the carrier 105 in the enclosure 103, a waveguide substrate 111 of the Mach-Zehnder modulator unit (modulator chip) 101 is disposed. On the carrier 105, a relay substrate 102a is mounted on one side and a terminal substrate 102b is mounted on the other side across the waveguide substrate 111.

The Mach-Zehnder modulator unit 101 includes electrodes 121 and an optical waveguide 112 formed on the waveguide substrate 111 made of an electrooptical crystal substrate, such as a LiNbO<sub>3</sub> (LN) substrate and a LiTaO<sub>2</sub> substrate or a semiconductor substrate, such as a GaAs substrate and an InP substrate.

The optical waveguide 112 includes an incoming waveguide 112a formed closer to an optical fiber 104a, parallel waveguides 112b (Mach-Zehnder interference units A and B) formed along the electrodes 121, and an output waveguide 112c.

Incoming light from the optical fiber 104a is branched by a branching unit 113 of the incoming waveguide 112a into branched beams of light incident on a pair of Mach-Zehnder interference units A and B (parallel waveguides 112A and 112B).

Each of the pair of Mach-Zehnder interference units A and B (parallel waveguides 112A and 112B) is branched into a pair of parallel waveguides 112b. The electrodes 121 are disposed parallel to the parallel waveguides 112b so that data on the electrodes 121 is transformed into data on an optical signal through a modulation process. The outgoing waveguide 112c downstream to the parallel waveguides 112b is equipped with a multiplexing unit 115, which multiplexes (by optical-polarization division) modulated components of

the optical signal from the pair of Mach-Zehnder interference units A and B and outputs the multiplexed signal to the optical fiber 104b.

An optical coupler may be used as the branching unit 113 and the multiplexing unit 115. The optical waveguide 112 on the end of the waveguide substrate 111 spatially propagates light through optical elements, such as lenses (not depicted), and is optically connected to the input-side optical fiber 104a and the output-side optical fiber 104b.

The electrodes 121 are formed as electrodes along the Mach-Zehnder interference units A and B (parallel waveguides 112A and 112B) of the optical waveguide 112. On both ends of the electrodes 121 corresponding to the Mach-Zehnder interference units A and B (parallel waveguides 112A and 112B), grounding electrodes (not depicted) are formed as coplanar electrodes.

In the example depicted in FIG. 1, one Mach-Zehnder interference unit A has two parallel waveguides 112A, along which two electrodes 121 are disposed. Therefore, corresponding to the pair of Mach-Zehnder interference units A and B, four electrodes 121 are disposed in total along pairs of parallel waveguides 112A and 112B. In the example depicted in FIG. 1, one Mach-Zehnder interference unit A and a pair of electrodes 121 form one set while the other Mach-Zehnder interference unit B and another pair of electrodes 121 form another set, and therefore two sets of the Mach-Zehnder interference unit and electrodes are formed. The electrodes 121 along the Mach-Zehnder interference units A and B have the same length (working length) L1 and are arranged parallel to each other.

The electrode substrate 102 depicted in FIG. 1 is formed by two substrates, i.e., the relay substrate 102a and the terminal substrate 102b that are disposed across the waveguide substrate 111 of the Mach-Zehnder modulator unit 101.

The relay substrate 102a is provided to lead the ends of the electrodes 121 to the enclosure (package) 103. The electrodes 121 include four RF electrodes 121a, four bias (first) DC electrodes 121b, four phase-adjusting (second) DC electrodes 121c, and two phase-adjusting (third) DC electrodes 121d.

Among these four RF electrodes 121a and four DC electrodes 121b, two RF electrodes 121a and two (bias) DC electrodes 121b are allocated to the one Mach-Zehnder interference unit A (pair of parallel waveguides 112A).

The connection configuration of the electrodes 121 will be described sequentially from the input side. Ends of the RF electrodes 121a are connected to RF terminals of the enclosure 103. Transmission data in the form of a high-speed electronic signal (microwave signal) is input to the RF terminals. To a pair of RF electrodes 121a corresponding to the one Mach-Zehnder interference unit A configured by a pair of parallel waveguides, given transmission data is input. To a pair of RF electrodes 121a corresponding to the other Mach-Zehnder interference unit B configured by another pair of parallel waveguides, other data is input separately.

The RF electrodes 121a are connected through the relay substrate 102a to the Mach-Zehnder modulator unit 101, on which an electronic signal is converted (modulated) into an optical signal through the part of optical waveguide 112 that serves as the Mach-Zehnder interference units A and B (parallel waveguides 112A and 112B).

The RF electrodes 121a extending from the Mach-Zehnder modulator unit 101 are connected to the terminal substrate 102b (first interconnect unit). On the terminal substrate 102b, each electrode 121 is branched into two (second interconnect units).

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Among the second interconnect units, one of the electrode **121** branches (first interconnect branch **121** Aaa) is connected to a terminal resistor ( $50\Omega$ ) **132** via a capacitor **131** and is terminated by the terminal resistor **132**.

The other of the electrode **121** branches (second interconnect branch **121** Aab) is connected to the DC electrode **121b** via a bias resistor **133** with a high resistance value (several hundreds  $\Omega$  to several k $\Omega$ ). This DC electrode **121b** is connected a DC terminal of the enclosure **103** via the terminal substrate **102b**, carrier **105**, and relay substrate **102a**. By applying a given voltage to this DC terminal and varying the applied voltage, a bias point of the Mach-Zehnder modulator unit **101** can be controlled.

On the rear part of the four parallel waveguides **112b** making up the pair of Mach-Zehnder interference units A and B (two pairs of parallel waveguides **112A** and **112B**), the phase-adjusting DC electrodes **121c** are disposed parallel to the four waveguides **112b** and are lead to the relay substrate **102a**. By applying voltage to the phase-adjusting DC electrodes **121c**, an off-point (operating point) of the Mach-Zehnder modulator unit **101** (Mach-Zehnder interference units A and B) can be phase-controlled.

In this manner, because the phase-adjusting DC electrodes **121c** are provided as electrodes independent of the above RF electrodes **121a**, the off-point (operating point) of the Mach-Zehnder modulator unit (modulator chip) **101** can be adjusted. In addition, a bias T (device for applying a phase-adjusting voltage without affecting an RF signal) externally connected to the RF electrodes **121a** can be omitted.

Parallel to the parallel waveguides **112b** (two pairs of parallel waveguides, i.e., four parallel waveguides making up the Mach-Zehnder interference units A and B), four off-point adjusting DC electrodes **121c** are disposed and are lead to the relay substrate **102a**. On the outgoing waveguide **112c**, the phase-adjusting (third) DC electrodes **121d** are disposed parallel to two waveguides, and are lead to the relay substrate **102a**. By applying a voltage to the phase-adjusting DC electrodes **121c**, the off-point (operating point) of the Mach-Zehnder modulator unit **101** (Mach-Zehnder interference units A and B) can be phase-controlled. By applying a voltage to the phase-adjusting DC electrodes **121d**, the phases of the pair of waveguides of the outgoing waveguide **112c** can be controlled so that the phases are set to be orthogonal to each other.

The wiring layout of the multiple electrodes **121** on the terminal substrate **102b** depicted in FIG. 1 will be described. Two electrodes **121A** (first group configured by electrodes **121Aa** and **121Ab**) making up one Mach-Zehnder interference unit A are bent on the terminal substrate **102b**, into an L shape in a first direction (X1 direction in FIG. 1) along the direction of travel of an optical signal.

The branching and arrangement of one electrode **121Aa** will be described along a signal path. The capacitor **131** and the terminal resistor ( $50\Omega$ ) **132** on one electrode **121Aa** branching from the electrode **121Aa** are arranged in the X1 direction. The bias resistor **133** on the other electrode **121Aab** branching from the electrode **121Aa** is disposed in the same X1 direction in which the capacitor **131** and the terminal resistor ( $50\Omega$ ) **132** are arranged. To the capacitor **131** and the terminal resistor **132**, the bias resistor **133** is disposed parallel along the width (Y) direction of the enclosure **103**. The capacitor **131**, the terminal resistor **132**, and the bias resistor **133** making up the other electrode **121** Aab are also arranged in the X1 direction and in the Y direction in the same manner as in the case of the electrode **121** Aa.

Meanwhile, two electrodes **121B** (second group configured by electrodes **121Ba** and **121Bb**) making up the other

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Mach-Zehnder interference unit B are bent into an L shape in a second direction (X2 direction in FIG. 1) opposite to the direction of bending (X1) of the electrodes **121A** (first group). The capacitor **131**, the terminal resistor **132**, and the bias resistor **133** making up the electrodes **121Ba** and **121Bb** are also arranged in the X2 direction.

In this manner, on the terminal substrate **102b**, wiring patterns of multiple (four) electrodes **121** are divided into two groups, i.e., a group of the electrodes **121A** and a group of the electrodes **121B**. The wiring pattern of one group of the electrodes **121A** (first group configured by the electrodes **121Aa** and **121Ab**) and the wiring pattern of the other group of the electrodes **121B** (second group configured by the electrodes **121Ba** and **121Bb**) are arranged in directions (X1 and X2 directions) opposite to each other along the length direction (X axis).

In the example depicted in FIG. 1, in a view along the length direction (X-axis), the one group of the electrodes **121A** (first group) are arranged at a position at which the electrodes **121A** overlap the working length L1 of the Mach-Zehnder interference units A and B. In this electrode layout as described above, arrangement of the bias resistors **133** requiring a given area in the directions opposite to each other on respective divided groups of electrodes is important. Because the bias resistors **133** have high resistance values (several hundreds  $\Omega$  to several k $\Omega$ ), a given area must be established for the bias resistors **133** on the terminal substrate **102b**. For this reason, the bias resistors **133** are arranged in distributed areas.

In this manner, by dividing the wiring patterns of four electrodes **121** into two groups along the length directions (X1 and X2) of the enclosure **103** in distributed arrangement, an increase in the size of the terminal substrate **102b** (along the X-axis direction) can be suppressed. The length L2 of the terminal substrate **102b**, therefore, can be reduced. Hence, the length of the enclosure **103** housing the terminal substrate **102b** can be reduced, thereby reducing the size of the enclosure **103**.

As depicted in FIG. 2, in the optical module **100**, a thermoelectric cooler (TEC) **201** and the carrier **105** are mounted in ascending order from the inner bottom face of the enclosure (package) **103**.

On the carrier **105**, the waveguide substrate **111** of the Mach-Zehnder modulator unit **101** is mounted. On the carrier **105**, the relay substrate **102a** is mounted on one side and the terminal substrate **102b** is mounted on the other side across the waveguide substrate **111** of the Mach-Zehnder modulator unit **101**.

On the surfaces of the relay substrate **102a**, the waveguide substrate **111** of the Mach-Zehnder modulator unit **101**, and the terminal substrate **102b**, the RF electrodes **121** (**121a**) are extended at the same level with an electrical connection between the relay substrate **102a** and the waveguide substrate **111** and an electrical connection between waveguide substrate **111** and the terminal substrate **102b** being formed by wire bonding **204**, etc.

The thermoelectric cooler **201** includes a temperature adjusting member, such as a heat sink and Peltier element, a temperature detecting element, and a control circuit, and controls temperature so that the carrier **105**, the relay substrate **102**, the terminal substrate **102b**, and the waveguide substrate **111** of the Mach-Zehnder modulator unit **101** mounted on the upper surface of the optical module have a constant temperature.

The electrodes **121** (RF electrodes **121a** and DC electrodes **121b**) of the relay substrate **102a** are lead to external terminals (not depicted) of the enclosure **103** via an input IF substrate **203**.

A route leading the bias DC electrodes **121b** from the terminal substrate **102b** to the DC terminals will be described. On the terminal substrate **102b**, the DC electrodes **121b** are lead from the other ends of the bias resistors **133** to the surface of the carrier **105** via the ends (side faces) of the terminal substrate **102b**. The DC electrodes **121b** are then extended as electrodes **105b** on the surface of the carrier **105** and are caused to pass under the Mach-Zehnder modulator unit (modulator chip) **101** (back surface opposite to the surface of the modulator chip **101**) and the relay substrate **102a**. The DC electrodes **121b** are then led out of the optical module via the DC terminals (more specifically, via the IF input substrate **203** depicted in FIG. 2).

In this manner, the DC electrodes **121b** do not pass over the surface of the Mach-Zehnder modulator unit (modulator chip) **101** but rather pass along the carrier **105**, disposed under (back surface of) the Mach-Zehnder modulator unit (modulator chip) **101** and are lead to the DC terminals.

It is therefore unnecessary to form the DC electrodes **121b** on the surfaces of the Mach-Zehnder modulator unit (modulator chip) **101** and relay substrate **102a**, thereby eliminating a need to create space for the DC electrodes **121b** to pass therethrough on the Mach-Zehnder modulator unit (modulator chip) **101**. Consequently, a reduction along the length L2 along the X-axis direction of the Mach-Zehnder modulator unit (modulator chip) **101** is achieved. No need of forming the DC electrodes **121b** also makes wire bonded connections, etc., unnecessary for causing the DC electrodes **121b** to pass along the Mach-Zehnder modulator unit (modulator chip) **101**, thereby saving trouble in the manufacturing process.

Because the electrodes **105b** formed on the surface of the carrier **105** are used as the DC electrodes **121b**, no layout restriction is imposed for establishing an area to arrange the DC electrodes **121b** on the Mach-Zehnder modulator unit (modulator chip) **101**. The electrodes **105b** on the surface of the carrier **105** can be laid out freely with any given wiring pattern without restriction.

In the example depicted in FIG. 1, the electrodes **105b** (DC electrodes **121b**) on the surface of the carrier **105** are laid out into a bent shape so that the position of the DC terminals for the DC electrodes **121b** is separated from the position of the RF terminals for the RF electrodes **121a**. In the example depicted in FIG. 1, the (group of) RF terminals for the four RF electrodes **121a** are arranged collectively in one location. The (group of) DC terminals for the four bias DC electrodes **121b** (and for the four phase-adjusting DC electrodes **121c** and two phase-adjusting DC electrodes **121d**) are arranged collectively in one location separated from the location of the RF terminals.

The four phase-adjusting DC electrodes **121c** and two phase-adjusting DC electrodes **121d** are formed on the surface of the Mach-Zehnder modulator unit (modulator chip) **101** and extend over the relay substrate **120a** through wire bonding, etc., to reach the DC terminals.

The RF terminals have to be provided using a large connector, such as coaxial connector, so that the prescribed pitch of the RF terminals is ensured to reduce crosstalk. The DC terminals, on the other hand, can be provided by using a small connector, enabling the pitch of the DC terminals to be narrow. As described above, arrangement of the DC electrodes **121b** can be performed freely. This allows the pitch of the RF terminals and of the DC terminals to be adjusted easily.

According to the first embodiment, therefore, the length L2 along the X-axis direction of the Mach-Zehnder modulator unit (modulator chip) **101** can be reduced, which allows a reduction in the size and cost of the optical module. This size reduction leads to a reduction in the loss of the Mach-Zehnder modulator unit (modulator chip) **101**, to an increase in the number of the waveguide substrates **111** produced from a single mold, and to improvement in the yield of the Mach-Zehnder modulator unit (modulator chip) **101**.

FIG. 3 is a top view of the optical module according to a second embodiment, and FIG. 4 is a side sectional view of the optical module according to the second embodiment. In the second embodiment, component units identical to those described in the first embodiment are denoted by the same reference numerals used in the first embodiment. The second embodiment differs from the first embodiment in a method of leading the bias DC electrodes **121b** (interconnect arrangement).

The method of leading the bias DC electrodes **121b** is described for the electrodes **121Aa** of the one Mach-Zehnder interference unit A. On the terminal substrate **102b**, the DC electrodes **121b** extend from the other ends of bias resistors **133** and are connected to the electrodes **105b** on the surface of the carrier **105** via the end (side face) **135** of the terminal substrate **102b**.

The carrier **105** is configured by a laminated substrate, on which the surface electrodes **105b** are connected to inner layer interconnects **105c** (indicated by dotted lines in FIG. 3) through vias **301**. These inner layer interconnects **105c** pass under the Mach-Zehnder modulator unit (modulator chip) **101** and the relay substrate **102a**, are connected to the DC terminals (more specifically, the input IF substrate **203** depicted in FIG. 4), and are lead out of the optical module.

According to the above configuration, it is unnecessary to establish space for the DC electrodes **121b** to pass therethrough on the surfaces of the Mach-Zehnder modulator unit (modulator chip) **101**. The Mach-Zehnder modulator unit (modulator chip) **101**, therefore, is not under layout restrictions for establishing an area to arrange the DC electrodes **121b** and therefore, can be reduced in length L2 along the X-axis direction. Wire bonded connections, etc., to extend the DC electrodes **121b** on the Mach-Zehnder modulator unit (modulator chip) **101** also become unnecessary, thereby saving trouble in the manufacturing process.

Freedom in layout the DC electrodes **121b** enables collective arrangement of the four bias DC electrodes **121b** and the phase-adjusting DC electrodes **121c** and **121d** at one location. The DC electrodes **121b**, **121c**, and **121d** arranged collectively at one location can be separated from the RF terminals arranged collectively at another location.

According to the second embodiment, the DC electrodes **121b** pass under the Mach-Zehnder modulator unit **101** and are lead out of the optical module, using the inner layer interconnects **105c** of the carrier **105**. Therefore, even in a configuration in which the back surface of the Mach-Zehnder modulator unit (modulator chip) **101** is metalized as a ground electrode, the DC electrodes **121b** can be lead out without short-circuiting at the Mach-Zehnder modulator unit **101**.

FIG. 5 is a top view of the optical module according to a third embodiment. The third embodiment differs from the second embodiment in a method of leading the bias DC electrodes **121b** (interconnect arrangement). In the second embodiment, the inner layer interconnects of the carrier **105** are used for the (bias) DC electrodes **121b** among the DC electrodes. In the third embodiment, however, the inner layer interconnects of the carrier **105** are used for all the DC electrodes **121b**, **121c**, and **121d**.

As depicted in FIG. 5, in the same manner as in the second embodiment, the bias DC electrodes **121b** are connected sequentially to the other ends of the bias resistors **133**, the ends (side faces) **135** of the terminal substrate **102b**, the electrodes **105b** on the surface of the carrier **105**, the vias **301**, the inner layer interconnects **105c**, and the DC terminals, and are lead out of the optical module.

The phase (off-point)-adjusting DC electrodes **121c** are lead from the four waveguides of the pair of Mach-Zehnder interference units A and B (parallel waveguides **112A** and **112B**) to vias **501** of the carrier **105**. The phase-adjusting DC electrodes are then lead from the vias **501** of the carrier **105** to the DC terminals via inner layer interconnects **105d** of the carrier **105**.

In a similar manner, the phase (orthogonal)-adjusting DC electrodes **121d** are lead from two waveguides making up the outgoing waveguide **112c**, to vias **502** of the carrier **105**. The phase-adjusting DC electrodes are then lead from the vias **502** of the carrier **105** to the DC terminals via inner layer interconnects **105e** of the carrier **105**.

According to the third embodiment, all the DC electrodes **121b**, **121c**, and **121d** are lead to the DC terminals, using the inner layer interconnects **105c**, **105d**, and **105e** of the carrier **105**. In this manner, the DC electrodes other than the RF electrodes **121a** can be laid out freely in wiring arrangement, using the inner layer interconnects **105c**, **105d**, and **105e**.

Freedom in the layout of the DC electrodes **121b** enables collective arrangement of the four bias DC electrodes **121b** and the phase-adjusting DC electrodes **121c** and **121d** at one location. The DC electrodes **121b**, **121c**, and **121d** arranged collectively at one location can be separated from the RF terminals arranged collectively at another location.

FIG. 6 is a top view of another optical module of the third embodiment. The optical module of FIG. 6 differs from the optical module of FIG. 5 in that the pitch of the RF electrodes **121a** is widened. In this manner, because the DC electrodes **121b**, **121c**, and **121d** can be laid out to be grouped together at one location, the arrangement space for the RF electrodes **121a** can be broadened. As a result, as depicted in FIG. 6, the pitch of the RF electrodes **121a** can be widened. Hence, the RF terminals using a large connector can be arranged with extra room.

FIG. 7 is a top view of the optical module according to a fourth embodiment, and FIG. 8 is a side sectional view of the optical module according to the fourth embodiment. According to the fourth embodiment, the multiple bias DC electrodes **121b** are lead out, using inner layer interconnects of different layers of the carrier **105** formed of the laminated substrate.

An example of two electrodes **121A** (first group) of the one Mach-Zehnder interference unit A will be described. The vias **301** (**301a** and **301b**) of the two DC electrodes **121b** are arranged at the same position in a view along the length (X-axis) direction but at different positions in a view along the width (Y-axis) direction.

As depicted in FIG. 8, the vias **301a** are connected to inner layer interconnects **105ca** of the carrier **105**, while the vias **301b** are connected to inner layer interconnects **105cb** of a layer different from a layer on which the inner layer interconnects **105ca** of the carrier **105** are formed, and are lead to the DC terminals. As depicted in FIG. 7, the inner layer interconnects **105ca** and **105cb** are formed at the same position in a view along the length (X-axis) direction but at different positions in a view along the height (thickness) direction of the carrier **105**.

Two electrodes **121B** (second group) of the other Mach-Zehnder interference unit B are also lead to the DC terminals using inner layer interconnects of layers formed at the same

position in a view along the length (X-axis) direction of the carrier **105** but at different positions in a view along the height (thickness) direction of the carrier **105**, in the same manner as in the case of the first group.

According to the fourth embodiment, for the carrier **105**, a space along the length (X-axis) direction necessary for leading (arranging) the bias DC electrodes **121b** can be reduced. As a result, the length L3 of the carrier **105** can be reduced to be shorter than the length L3 of the first to third embodiments.

FIG. 9 is a top view of the optical module according to a fifth embodiment, and FIG. 10 is a side sectional view of the optical module according to the fifth embodiment. The fifth embodiment is a modification of the fourth embodiment and relates to a configuration in which the terminal substrate **102b** described in the fourth embodiment and the carrier **105** are integrated. Aside from this aspect, the fifth embodiment is the same as the fourth embodiment, achieving a configuration in which the multiple bias DC electrodes **121b** are lead out, using inner layer interconnects of different layers of the carrier **105** formed by the laminated substrate.

As depicted in FIG. 10, a recess (groove) **1002a** as deep as the height of the relay substrate **102a** and the waveguide substrate **111** of the Mach-Zehnder modulator unit (modulator chip) **101** is formed on the surface of the carrier **105**, and the relay substrate **102a** and the waveguide substrate **111** of the Mach-Zehnder modulator unit (modulator chip) **101** are placed in the recess **1002a**. As a result, the surface (electrode position) of the waveguide substrate **111** placed in the recess (groove) **1002a** and the surface (electrode position) of the carrier **105** placed in the recess (groove) **1002a** can be set to be flush with each other.

According to the fifth embodiment, because the terminal substrate and the carrier **105** are integrated together, the number of components is reduced, packaging precision is improved, and easier management is achieved. Improved packaging precision leads to improved modulation characteristics.

FIG. 11 is a top view of the optical module according to a sixth embodiment. This optical module **100** of the sixth embodiment is a configuration example of a DP-DPSK optical modulator different from the QPSK modulator of the first to fifth embodiment. According to the sixth embodiment, one waveguide making up the outgoing waveguide **112c** is equipped with a polarization rotating unit **1101** that rotates the direction of polarization to set the polarization to be perpendicular to the direction of polarization by the other waveguide of the outgoing waveguide **112c**. The multiplexing unit **115** is equipped with a polarized wave synthesizing unit **1102**. In each of the first to sixth embodiments, the outgoing waveguide **112c** may be selectively provided with the phase adjusting mechanism of the first to fifth embodiments or the polarization adjusting mechanism of the sixth embodiment for adoption of a selected modulation method.

FIG. 12 is a block diagram of a configuration example of an optical transmitter according to a seventh embodiment. An optical transmitter **1200** includes the optical module **100** of the above embodiments, a data generating unit **1201**, and a laser diode (LD) light source **1210**. The data generating unit **1201** may be configured by, for example, a digital signal processor (DSP). The data generating unit **1201** outputs incoming transmission/reception data (two separate data) in the form of a high-speed microwave signal (electronic signal), to the RF electrodes **121a** of the optical module **100**. The generating unit **1201** also controls the bias point of the Mach-Zehnder interference units A and B via the DC electrodes **121b** of the optical module **100**. In the configuration example of the QPSK modulator, the generating unit **1201** controls the

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off-point via the DC electrodes **121c** and performs quadrature phase control via the DC electrodes **121d**.

In the configuration example of the DP-DPSK modulator, a bias control circuit **1202** performs polarization control over the polarization rotating unit **1101** and the polarized wave synthesizing unit **1102** so that the direction of polarization of light at the pair of parallel waveguides **112A** and the direction of polarization of light at the pair of parallel waveguides **112B** become orthogonal to each other. A temperature control unit **1203** responds to environmental temperature change, etc., controlling the temperature adjusting cooler **301** so that the optical module **100** remains at a constant temperature.

Light from the LD light source **1210** is input to the optical module **100**, which multiplexes two separate data through the pair of Mach-Zehnder interference units A and B by the above modulation method (QPSK, DP-DPSK, etc.) and outputs multiplexed signals from the optical fiber **104b**.

In each of the second to fifth embodiments, when the configuration of using the inner layer interconnects of the carrier **105** for leading the DC electrodes **121b** is adopted, the bias resistors **133** may be disposed on the inner layer interconnects. Since the bias resistors **133** have high resistance values (several hundreds  $\Omega$  to several  $k\Omega$ ), sufficient space for disposing the bias resistors **133** is needed. If the bias resistors **133** of a given length are disposed on the inner layer interconnects **105c** of the carrier **105**, space for mounting the bias resistors **133** on the carrier **105** can be reduced. Hence, the size along the width (Y-axis) direction of the carrier **105** can be reduced by a portion equivalent to the bias resistors **133**, which are not disposed on the carrier **105**.

The terminal resistors **132** have small resistance values and are compact, thus taking less space. Disposing the capacitors **131** on the inner layer interconnects **105c** of the carrier **105** is difficult.

The bias resistors **133** may be disposed on the back surface of the terminal substrate **102b** or of the carrier **105**. It is also possible to form vias on the terminal substrate **102b** or the carrier **105** so that the bias resistors **133** can be disposed on the back surfaces of the terminal substrate **102b** or the carrier **105**. In these cases, the space for mounting the bias resistors **133** on the carrier **105** can be reduced.

In each of the first to fifth embodiments, the bias resistors **133** are arranged such that the bias resistors **133** are shifted along the Y-axis direction so as not to overlap the capacitors **131** and the terminal resistors **132**. In contrast, if the bias resistors **133** are disposed on the inner layer interconnects or the back surface of the carrier **105** or of the terminal substrate **102b**, the size of the mounting space on the surface of the carrier **105** or terminal substrate **102b** can be reduced along the Y-axis direction by a portion equivalent to the bias resistors **133** (and DC electrodes **121Aab**). Hence, the size along the width (Y-axis) direction of the carrier **105** can be reduced.

Even if the DC electrodes **121b** are disposed on the carrier **105** or terminal substrate **102b**, such a configuration does not affect the (RF) electrodes **121a** for high-frequency signals and enables the high-frequency characteristics of a high-speed microwave signal to be maintained.

FIG. **13** is a top view of a configuration example of another optical module for comparison with the optical module of the embodiments. FIG. **13** depicts a configuration example in which a pair of the Mach-Zehnder interference units A and B (working length L1) are disposed adjacent to each other on a modulator chip **1302** and the above electrode terminals and electronic components (capacitors **1311**, terminal resistors **1312**, bias resistors **1313**) are arranged on a relay substrate **1301**.

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An optical modulator **1300** depicted in FIG. **13** has a configuration in which the electronic components (capacitors **1311**, terminal resistors **1312**, bias resistors **1313**) on multiple electrodes are simply arranged in parallel along the X-axis direction. To enable this arrangement of the electronic components (capacitors **1311**, terminal resistors **1312**, bias resistors **1313**), the bias DC electrodes **1321** have to be a length L11.

In this manner, when all electrodes are disposed on the surface of the modulator chip **1302**, the length L13 of the modulator chip **1302** must be the total of the working length L1, the length L10 of RF electrodes **1320**, the length L11 of DC electrodes **1321**, and the length L12 of DC electrodes **1322** and **1323**. The longitudinal size of the modulator chip **1302**, therefore, is increased, which consequently increases the longitudinal size of an enclosure **1303**.

In the configuration depicted in FIG. **13**, the lengths of electrodes (working length L1) on the Mach-Zehnder interference units A and B differ from one another. It is therefore necessary in actual application to determine the lengths of multiple electrodes disposed parallel to each other on the optical waveguides to be identical and to dispose an electrode of the working length L1 or greater in a location deviated from the optical waveguide.

According to the optical module **100** of the above embodiments, as depicted in FIG. **1**, etc., the DC electrodes **121b** (and the DC electrodes **121c** and **121d** of FIGS. **5** and **7**) do not pass over the surface of the modulator chip **101** (waveguide substrate **111**) but rather pass under the modulator chip **101**, using the interconnects on the carrier substrate **105**. This eliminates the need of establishing space for the DC electrodes **121b** to pass therethrough, thus enabling a reduction along the length of the modulator chip **101** by a portion equivalent to the length L11 of FIG. **13**.

On the terminal substrate **102b**, multiple electrodes **121** are distributed along the length (X-axis) direction (i.e., divided into two groups that are arranged opposite to each other). The electrodes **121** distributed along the length direction are located at the positions at which the electrodes **121** overlap the working length L1 required by the Mach-Zehnder interference units A and B along the length direction. As a result, on the terminal substrate **102b**, the electrodes **121** necessary for arrangement of the electronic components to be mounted (capacitors **131**, terminal resistors **132**, bias resistors **133**) can be shortened along the length direction.

If the inner layer interconnects of the carrier **105** are used for the other electrodes **121Aab** branching from the electrodes **121Aa** and the bias resistors **133** are disposed on the inner layer interconnects, the arrangement space for the bias resistors **133** to be disposed on the other electrode **121Aab** can be positioned efficiently. As a result, the width of the terminal substrate **102b** can be reduced, which leads to further size reductions of the optical module.

While the optical modulator has been described as an example of the optical module in each of the above embodiments, the optical module may also apply to an optical switch that has the same configuration as the configuration of the optical module and that performs switching operations through reversal of the voltage applied to the electrodes **121**.

According to an embodiment, the size of an optical module can be reduced.

All examples and conditional language provided herein are intended for pedagogical purposes of aiding the reader in understanding the invention and the concepts contributed by the inventor to further the art, and are not to be construed as limitations to such specifically recited examples and conditions, nor does the organization of such examples in the

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specification relate to a showing of the superiority and inferiority of the invention. Although one or more embodiments of the present invention have been described in detail, it should be understood that the various changes, substitutions, and alterations could be made hereto without departing from the spirit and scope of the invention. 5

What is claimed is:

1. An optical module comprising:

a waveguide substrate including an optical waveguide and a plurality of electrodes that apply an electronic signal to the optical waveguide;

a relay substrate disposed adjacent to the waveguide substrate;

a terminal substrate disposed adjacent to the waveguide substrate and opposite to the relay substrate across the waveguide substrate; and

a carrier substrate on which the waveguide substrate, the relay substrate, and the terminal substrate are mounted, wherein

the plurality of electrodes have a first interconnect unit extending from the relay substrate to the terminal substrate via the waveguide substrate and second interconnect units extending from the first interconnect unit and branching on the terminal substrate,

a first interconnect branch among the second interconnect units includes a capacitor and a terminal resistor, and

a second interconnect branch among the second interconnect units is connected to an interconnect of the carrier substrate via a bias resistor, passes under the waveguide substrate, and extends to a DC electrode for bias-adjusting on the relay substrate. 25

2. The optical module according to claim 1, wherein an interconnect of the carrier substrate is disposed on a surface of the carrier substrate. 35

3. The optical module according to claim 1, wherein the carrier substrate is a laminated substrate, and an inner layer interconnect of the carrier substrate is used for an interconnect of the carrier substrate.

4. The optical module according to claim 2, wherein an inner layer interconnect of a different layer of the carrier substrate and corresponding to the plurality of electrodes, is used for the second interconnect branch. 40

5. The optical module according to claim 4, wherein an inner layer interconnect at an identical position in a different layer of the carrier substrate is used for the second interconnect branch. 45

6. The optical module according to claim 1, wherein the terminal substrate and the carrier substrate are integrated. 50

7. The optical module according to claim 6, wherein a recess in which the waveguide substrate and the relay substrate are disposed is formed on a surface of the carrier substrate.

8. The optical module according to claim 1, wherein the second interconnect units are divided into a first group extending in a first direction along the optical waveguide and a second group extending in a direction opposite to the first direction. 55

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9. The optical module according to claim 1, wherein the plurality of electrodes that apply an electronic signal to the optical waveguide include a plurality of RF electrodes that apply a high-frequency electronic signal for modulation and a plurality of the DC electrodes, the plurality of RF electrodes is collectively arranged as an RF terminal group on the relay substrate, separately from a DC terminal group of the DC electrodes.

10. The optical module according to claim 9, wherein the RF terminal group is arranged to have a pitch that is wider than a pitch of the DC terminal group, and the second interconnect branch is arranged in a layout corresponding to the pitch of the DC terminal group.

11. The optical module according to claim 1, wherein the waveguide substrate includes a phase-adjusting DC electrode disposed along the optical waveguide, the phase-adjusting DC electrode is extended to the relay substrate via an interconnect of the carrier substrate.

12. An optical transmitter comprising:  
an optical module configured to include:

a waveguide substrate including an optical waveguide and a plurality of electrodes that apply an electronic signal to the optical waveguide;

a relay substrate disposed adjacent to the waveguide substrate;

a terminal substrate disposed adjacent to the waveguide substrate and opposite to the relay substrate across the waveguide substrate; and

a carrier substrate on which the waveguide substrate, the relay substrate, and the terminal substrate are mounted, wherein

the plurality of electrodes have a first interconnect unit extending from the relay substrate to the terminal substrate via the waveguide substrate and second interconnect units extending from the first interconnect unit and branching on the terminal substrate,

a first interconnect branch of the second interconnect units includes a capacitor and a terminal resistor, and

a second interconnect branch of the second interconnect units is connected to an interconnect of the carrier substrate via a bias resistor, passes under the waveguide substrate, and extends to a DC electrode for bias-adjusting on the relay substrate;

a data generating unit configured to supply separate transmission data as the electronic signals, to the plurality of electrodes, and supply a drive signal for modulation through the optical waveguide; and

a bias control circuit that performs control so that polarization directions of light at the optical waveguide become orthogonal to each other.

13. The optical module according to claim 3, wherein an inner layer interconnect of a different layer of the carrier substrate and corresponding to the plurality of electrodes, is used for the second interconnect branch.

14. The optical module according to claim 13, wherein an inner layer interconnect at an identical position in a different layer of the carrier substrate is used for the second interconnect branch.

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